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PLANTING STOCK QUALITY MONITORING

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ABSTRACT

Methods of evaluating and monitoring planting stock quality are assessed, and seedling quality attributes are identified and discussed. An extensive review of literature relating to stock quality evaluation and methods of evaluation is presented.

RESUME

Les méthodes d'évaluations et de contrôle de la qualité des semis sont evaluées et les attributs de la qualité des semis sont identifiés et discutés. Une revue poussée de littérature sur l'évaluation de la qualité des semis et les méthodes d'évaluations est présentée.

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INTRODUCTION

Over the last decade there has been a rapid increase in tree nursery capacity and tree planting programs in Alberta, Saskatchewan, and Manitoba. The number of seedlings being planted each year increased from about 7 million in 1972 to 30 million in 1980 and 57 million in 1983 (Brace 1981; Smyth and Brownwright 1984). Since 1978 new nurseries have been established and existing nurseries expanded. Bare-root nurseries in the region produced about 34.3 million seedlings in 1985.

The need to produce and plant more trees over large areas has heightened concern about plantation establishment, seedling mortality in plantations, and the long-term success of reforestation programs. Though not all plantation problems are traceable to planting stock quality, the importance of high-quality stock has increased correspondingly. It is now widely appreciated by both foresters and nurserymen that good quality seedlings are critical to the growth and survival of forest plantations.

The constant production of high-quality seedlings is made difficult by the complexity of growing seedlings in what is largely an uncontrolled environment. The lack of a rational framework of established standards by which to define high-quality planting stock, and inadequate communication regarding the performance of planted seedlings, makes its attainment even more difficult.

SEEDLING STOCK QUALITY

The definition of stock quality and approaches to its monitoring vary. The term *stock quality* is often used loosely, and confusing interpretations abound. Planting stock is often described only by a stock type or by a stock type and one or two size characteristics. The prior definition of seedling stock quality traits makes it difficult to correlate seedling characteristics with field performance and to interpret variations in stock performance. Furthermore, this inadequate practice hinders essential communication about stock quality between nursery and field personnel.

The interprovincial Regional Reforestation Technical Committee, which provides coordination of research needs and the exchange of operational reforestation information among Alberta, Saskatchewan, and Manitoba, has expressed a concern about the lack of a consistent basis for interpreting reforestation results. The committee has recognized the need for a review of stock quality procedures used in provincial nurseries and for the possible development of a standardized stock quality monitoring system in the prairie region.

As an initial stage in meeting these needs, a survey and review of the methods and scope of bare-root seedling quality monitoring currently in use in the nurseries of the prairie provinces was undertaken with the following overall objectives:

1. to facilitate the exchange of information among the provincial nurseries about the monitoring of planting stock quality;
2. to compare the methods of stock quality monitoring currently in use; and
3. to provide a basis for standardization of the methods used in stock quality monitoring, thus facilitating comparison of the outplanting performance of various types of bare-root seedling stock.

A questionnaire was developed (Appendix 1) and sent out to the provinces' forestry departments. This report presents a summary of the responses together with a review of pertinent literature, an analysis of present-day stock quality assessment technology, and a comparison of available technology with current practices. It is from this basis that the concluding recommendations for the monitoring of stock quality in the prairie provinces are presented. It is hoped that these recommendations take into consideration regional nursery requirements and will speed the development of both provincial and regional bare-root stock quality standards and monitoring programs.

What is stock quality?

Discussions of nursery stock quality are often clouded by generalities, perhaps because accurate, succinct, and acceptable definitions of stock quality have been rare. As pointed out by Sutton and Tinus (1983), the term *quality* has been used with several disparate meanings, some implying measurable characters and others suggesting vague qualitative impressions. In some usages, quality is equated with excellence. These

examples illustrate well how freely and loosely the term *stock quality* has been used by foresters and nurserymen alike.

At the 1979 IUFRO (International Union of Forestry Research Organizations) workshop, "Techniques for evaluating planting stock quality"[1], the quality of planting stock was defined as the degree to which planting stock realizes the objectives of management: quality is fitness for purpose. This definition implies that the clear expression of management objectives is a prerequisite to any determination of the quality of planting stock (Sutton 1979).

Indirectly, it also means that the determinants of stock quality must be responsive and able to adjust to new or changed objectives. Because survival and growth performance of planting stock are the outcomes of interactions between stock quality and site, the stock standards should be tailored to fit the demands of a particular site or reforestation alternative. Trade-offs between stock quality and sites or site preparation have been suggested and implemented in reforestation programs (Dobbs 1976).

The term *seedling quality* as used in this report expresses the potential of a seedling to survive and grow after outplanting. This potential is determined by a multitude of physiological and morphological characteristics, some of which are measurable while others are undetectable with current technology. The measurable attributes can be used to quantify seedling quality, and in combination they can be used to predict the survival and growth potential of a seedling or batch of seedlings.

How can a seedling's quality be evaluated?

Around the world, a wide range of criteria and characteristics is used to assess seedling quality. Traditionally, the criteria are grouped into two categories: morphological and physiological. Until fairly recently, seedling quality criteria were based solely on morphological qualities. Physiological quality is more complex and much more difficult to measure, and although its importance was recognized over 30 years ago (Wakeley 1948), measurement techniques have been largely developed only within the last decade.

An obvious question arises here: is there a quality characteristic that is most relevant to field performance and that should be preferentially monitored in stock quality programs? Unfortunately, there is no universal agreement, and likely cannot be, on a specific characteristic that is most useful. No consistent survival and growth differences can be attributed to a single characteristic. A good analogy illustrating this point is in the following comparison of human health and seedling quality (Ritchie 1984):

> When examined by a physician, the patient is subjected to a battery of measurements—some simple and others highly sophisticated. It is from the collective results of these tests, not just one test alone, that the physician is able to characterize the patient's general health. As there is no one index of human health, there is no one yardstick of seedling quality.

Stock quality evaluation can only be based on an array of assessment procedures, each providing information on certain aspects of seedling quality. Because the effects of specific quality factors can be confounded by other factors, no characteristic should be considered and interpreted in isolation.

What evaluation methods should be included?

The scope of a stock monitoring program should be governed by the requirements of its allied reforestation program. Stock quality, consequent seedling performance, and the evaluation of both should meet these requirements. A basic program of minimum scope should always be maintained to ensure that the fundamental objectives of quality control in the reforestation program are fulfilled. Only a small number of quality criteria may be needed to conclude, for example, that the stock is definitely in poor shape and that the seedling mortality after outplanting will be high. Quality criteria can be added depending upon the quality of product required, the type of operation and products of each nursery, and the sites to be planted. Criterion selection will depend upon the history and strengths and weaknesses of a given crop and should be supported by dialogue between field foresters and nurserymen (Duryea 1984; Iverson 1984). For example, if the major stresses to be endured by a crop of outplanted seedlings are expected to be drought and frost, then water stress resistance and frost resistance tests should be included in the quality assessment. Economy and ease and efficiency of quality monitoring methods should also be considered, and a balance between the desirable, the affordable, and the necessary will have to be struck.

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[1] In a special 1980 issue of the New Zealand Journal of Forestry Science 1(10).

Many methods and procedures to assess planting stock are available to the nursery manager, and researchers have gathered a lot of data that can help in the evaluation of stock quality. A number of reports have been published about techniques ranging from simple field trials to sophisticated laboratory procedures. Several comprehensive reviews are available on the topic (such as Jaramillo 1980; Ritchie 1984; Day et al. 1985).

Obviously a great deal of information needed to develop or upgrade stock monitoring programs is already available, but it must still be packaged in a form that will facilitate optimal use. Technology transfer from researcher to operations worker and a bridge between the scientific and the practical must be encouraged. Some methods have been designed for research purposes but cannot be readily adapted for operational use or require more calibration. Many other procedures appear to be too complex, time-consuming, or laboratory-demanding to make them practical.

All of the techniques described in the available literature are reviewed in this report. In the following sections, an assessment of each technique with regard to its operational utility and limitations is presented. Representative techniques and methods are briefly described, and the most-pertinent sources are referenced. The most-relevant methods and those that seem most promising for operational monitoring programs are described in detail.

SEEDLING QUALITY ATTRIBUTES

Morphological attributes

In the past, quality control in nurseries was based almost exclusively on morphological criteria: the size, shape, and general appearance of a seedling. In fact, many current provincial specifications for nursery stock and minimum standards for acceptable seedlings are based entirely on morphological criteria. In low-stress outplanting situations (Sutton 1979) and with a minimized handling and lifting-planting cycle (Albert et al. 1980), this system works tolerably well.

Benefits frequently accrue from planting large seedlings with highly ranked morphological grades. Factors such as shoot height, stem diameter, root volume, length and mass shoot:root ratio, and sturdiness (height and stem diameter) have all been shown to be predictors of growth and survival under specific site and planting conditions (Chavasse 1980; Schmidt-Vogt 1981; Mullin and Christl 1982). The concept that larger is better for outplanted seedlings, however, belies a complex relationship, and the variable results of using only morphological characteristics to predict survival and growth have caused much dissatisfaction and confusion. The observation of Schmidt-Vogt (1981) that mortality is higher for large than for small seedlings in the year of outplanting, but higher for small than for large plants in subsequent growing seasons, appears to reflect a common pattern (Lavender and Hermann 1976). Large plants suffer from greater postplanting shock; however, after the initial years, they are superior in growth to smaller plants, which are more susceptible to weed competition. Comparisons between morphological traits of large and small stock are valid only when different-sized seedlings are under the same physiological conditions when tested (Van den Driessche 1976a). According to Ritchie (1984), this simple prerequisite is rarely satisfied, which might invalidate much of the published research about the effects of morphology on seedling performance. In stressful outplanting situations or with other than minimally-stressed planting stock, morphological criteria are inadequate and misleading indicators of performance (Sutton 1980). To illustrate this using an extreme example, morphological criteria can be measured on a dead seedling.

Morphological characteristics have their place in quality monitoring and will likely be retained as its most important component. A trend is occurring toward replacing time-consuming morphological characteristics with more easily measurable characteristics. Height and root collar diameter (RCD) are commonly accepted as the most suitable morphological criteria. Root collar diameter alone has a predictive value; in general the larger the RCD, the more successful an outplanting will be. Close correlation between RCD and survival and growth has been documented for several species (Blair and Cech 1974; Albert et al. 1980; Chavasse 1980), but again it is unwise to use RCD as a single criterion of vigor (Armson and Sadreika 1979; Day 1980; Day and Harvey 1983). A combination of height and RCD is widely accepted as a valid indicator of postplanting performance; for example, it is used to specify the minimum standards for morphological grading of forest nursery stock in the European Economic Community. Other combinations of height, RCD, and root quality would seem desirable, but various attempts to provide indexes of quality by mathematically combining several characteristics such as the seedling index proposed by Armson and Sadreika (1979) and the quality indexes suggested by Dickson et al. (1960) and Iyer and Wilde (1982) have not gained much practical acceptance.

The top/root ratio has been used for many years to characterize stock. The top/root ratio is commonly determined from top and root ovendry weights, though the nondestructive and faster volume displacement methods produce equally good results and are more economical (Burdett 1979; Glerum and Boufford 1979). The practicality of using top/root ratios in nursery stock characterization was critically examined by Racey et al. (1983). They concluded that the top/root ratio is of little value in nursery evaluation because it does not reflect the balance between top and root needed for optimum field performance. The controversial value of the top/root ratio coupled with the limited availability of volume displacement methods appears to limit the usefulness of dry weight determinations in a quality monitoring program.

The quality of a seedling's root system—its size and fibrosity—is a critical attribute of stock quality. Physiological quality (root growth potential) and incidence of mycorrhizae (Navratil 1981), however, may override the effects of root system morphology and size. Root system size can be measured either in area, using photometric devices such as rhizometers (Morrison and Armson 1968), or in volume, using graduated cylinders or gravimetric methods (Burdett 1979). No convenient and practical method for quantifying fibrosity of a root system is available, though root area index measured by a rhizometer does provide to some extent an indicator of root system fibrosity and more closely corresponds to the absorbing surface of a root system than do root volume measurements.

A unique and viable system for classifying nursery stock was developed by Day (1980). The system integrates height, RCD, and root area index measurements and provides a means of evaluating stock by comparing it to predetermined values of normal stock. Once the characteristic measurements of normal are established (a process that requires measurement of a considerable number of stock produced over several years), this system allows fast evaluation of broad morphological quality classes. The classes separate small from larger seedings and distinguish between top-to-root balanced and imbalanced stock.

Culling and inadvertent favoring of certain morphological traits can change the genotypic mixture represented in a seed lot. Culling for height and diameter will partly remove inbred plants that are small, weak, and potentially aberrant. Culling inbreds therefore probably increases the range of adaptability and improves the growth potential of a seed lot. If heavier than normal culling (i.e., 10–30% of seedlings are discarded) is practiced, a substantial shift in genotypic values can be expected (Campbell and Sorenson 1984).

Root growth potential

The dependence of field-planted seedling survival and subsequent shoot growth upon the rapid establishment of a vigorous root system is well recognized. Though some of the variation in root growth observed on a planting site can be explained by soil temperature (Thompson and Timmis 1978) and water availability (Stone and Jenkinson 1970; Day and MacGillivray 1975; Ritchie and Dunlap 1980), the physiological readiness of a seedling to produce new roots is critical. This physiological attribute—a seedling's ability to grow new roots, or root growth potential (RGP)—can be assessed in a test environment and expressed quantitatively. There is sufficient evidence that survival and growth of planted trees are correlated with laboratory-determined RGP and that RGP measured prior to planting is a key predictor of seedling vigor and performance (McMinn 1980; Burdett et al. 1983). The correlation, however, can be site-specific (Sutton 1983; Day and Harvey 1984). The method of RGP measurement is therefore of primary interest when planning a stock quality monitoring program.

The concept of measuring RGP is fairly straightforward. Seedlings are potted in a growing medium or placed in a mist chamber and held in a test environment under ideal conditions for root growth. After a predetermined period, new root production is quantified. The standard method of measuring RGP (Stone et al. 1962; Day 1982; Ritchie 1984) involves potting of seedlings, holding of potted seedlings in a greenhouse for a specific period of time (usually 28 days), washing of the roots, and then counting of new roots. Modifications of this standard method to avoid the need for potting and particularly to shorten the 1-month delay in obtaining results have led to several improvements in the procedure. Instead of using pots containing a soil substrate, seedlings can be placed in a water bath (Ritchie 1984) or misting chambers. Root misting techniques are easily conducted and also allow RGP to be measured while the test is in progress (Day et al. 1985). A misting chamber fitted with spray jets controlled by a programmed time clock has been used in research projects (Day and Harvey 1983). A modified design of aeroponic root mist chambers[2] is

[2] Harvey, E.M.; Day, R.J. 1983. Evaluating the root regeneration potential of coniferous nursery stock by the potting and root mist chamber methods. Lakehead Univ. Sch. For., Thunder Bay, Ont. Unpublished report.

fitted with a plastic impellor that sucks up water by centrifugal force and provides the seedlings with a fine constant mist. The Alberta Forest Service's Research Branch currently uses an aeroponic misting chamber constructed according to a design developed by Hubick et al. (1982) of the Department of Biology at the University of Calgary.

The time needed for RGP tests can be shortened by forcing root growth with high temperatures. Burdett (1979) recommended conditions that accelerated root growth in lodgepole pine and reduced the RGP test time from 1 month to 1 week. Comparisons of 10-day and 21-day tests of RGP using several boreal tree species concluded that a 10-day test adequately predicts the RGP test result of stock after 21 days[3].

Root growth potential can be expressed as the total number of new roots or total length or volume of new roots (Burdett 1979). For practical purposes counts of new roots are adequate, and a scoring system as developed by Burdett (1979) for lodgepole pine could be adapted for other species to improve this simple assessment method. For research work, the number of new roots and their length, which reflect the distinct physiological processes of root initiation and elongation, respectively, should be recorded[4] (Thompson and Timmis 1978). Estimates of RGP using root area index and root volume measurements can result in an underestimation due to root shedding (Day and Harvey 1984).

Several issues must be addressed before RGP can be used routinely and with confidence in nursery stock quality monitoring. The most important point is that to be comparable with each other, RGP values must be obtained by adhering to standardized procedures and using controlled environments to hold test seedlings. In the test environments, conditions such as temperature and moistness of potting medium, air temperature, and photoperiodicity can have a substantial influence on RGP tests. The temperature around roots exerts a major influence on new root growth. Root development proceeds most favorably between 18 and 25°C, depending upon the species. Boreal tree species likely have lower optima, although these have not yet been determined. Cold water temperature in a root misting chamber (Harvey and Day 1983) may reduce RGP, and the frequency of misting affects the RGP of dormant and freshly lifted seedlings differently. Because of considerable variation in RGP values among individual seedlings[5], treatment sample size should be a minimum of three to five replications of five seedlings each (Ritchie 1984). In addition, handling of stock and storage conditions prior to tests affect the degree to which actual RGP is expressed. For this reason, in order to be valuable in estimating stock performance, RGP tests should be conducted prior to the shipment of stock from the nursery or better, shortly before planting.

Root growth potential tests are a very valuable tool for assessing the overall quality of seedling stock. They can provide critical information for matching lower quality stock to appropriate site conditions or for discarding economically unplantable stock. Efforts should be made to facilitate the incorporation of RGP tests into reforestation and monitoring programs. Before any comparisons of RGP will be possible it will be necessary to adapt and standardize test conditions, probably with the use of comparable equipment, e.g., greenhouses or growth chambers, and to refine the criteria for testing seedlings of boreal tree species. Without this essential standardization of RGP tests in the region, the interpretation of RGP and the use of RGP comparisons in reforestation programs may not be possible.

Stress resistance

Seedlings that grow well in spite of the harsh environment into which they are outplanted are termed *stress resistant, hardy,* or *vigorous* (Timmis 1980). Operational circumstances and weather often compromise optimum seedling nursery production and outplanting establishment, so foresters could make good use of a reliable test of the quality or vigor of planting stock. The aim of such a test would be to eliminate the economic losses that result when planted stock dies. In addition to the root growth potential measurement that can be used to estimate field survival, other techniques for assessing a seedling's overall physiological vigor and potential for survival have been explored.

A simple technique for testing the vigor of conifer planting stock has been developed in Oregon (Hermann and Lavender 1979). This test assesses the effect of a

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[3,4,5] Harvey, E.M.; Day, R.J. 1983. Evaluating the root regeneration potential of coniferous nursery stock by the potting and root mist chamber methods. Lakehead Univ. Sch. For., Thunder Bay, Ont. Unpublished report.

standard dehydration stress on subsequent seedling survival in a standard greenhouse environment. After exposure for 15 minutes at 32°C and 30% relative humidity, the seedlings are potted and placed alongside control seedlings in a greenhouse. Mortality of seedlings is evaluated after 2 weeks, 1 month, and 2 months, and seed lots are classified as poor, fair, good, or excellent. The test is designed so that mortality of the stressed seedlings should correspond roughly to expected field mortality. Under normal conditions poor lots should not be planted and fair lots should be planted only in areas where severe stress will not be encountered. Field performance correlated well with seedling lots displaying either very high or very low test mortality (Ritchie 1984).

This technique seems to have considerable potential for detecting severe declines in the quality of stock and appears to be useful in making decisions that could save foresters a lot of money. Before it can be used routinely, however, calibration of evaluation classes pertinent to boreal tree species will be required.

Water status

Seedling water status is a critical physiological function that can easily be measured with the pressure bomb (pressure chamber). Use of the pressure bomb for measuring seedling water stress has been validated by many studies as both a research tool and a practical device (Waring and Cleary 1967; Cleary 1971; Ritchie and Hinchley 1975; Ruetz 1980). Fast, reliable, and accurate measurements can be made easily both in the laboratory and in the field.

A pressure bomb measures the pressure required to force internal water in tissue to the cut surface of a stem, twig, shoot, or root. That pressure, which is recorded from a gauge, estimates xylem water potential expressed in pressure units—pounds per square inch, atmospheres, or bars. It should be remembered when interpreting the results that these units are used interchangeably and that in scientific literature that uses the SI or metric system, the pascal, kilopascal, and megapascal units can be found. In most work with forest tree seedlings, water potential of shoots and branches is measured, although root water potential can also be assessed. Measuring the water potential of needles rather than that of branches enables repeated assessment of the same seedling (Ritchie 1984). The method for use of a pressure bomb, including safety precautions, has been detailed in several reports (Cleary and Zaerr 1980; Day and Walsh 1980; Day et al. 1985). A further development of the pressure bomb method involves measurement of osmotic and turgor potentials through generation of pressure-volume curves (Gross 1980; Ritchie 1984).

Plant moisture stress, as determined by the pressure bomb, is perhaps the most promising general index of plant condition and potential performance. Low levels of plant moisture stress ensure vigorous seedlings and thus high survival potential. Because the method provides immediate results, it is an ideal technique for monitoring and detecting moisture stress buildup during lifting, grading, packing, and storage of seedlings and for checking the condition of seedlings on a planting site. The measurement of water potential is a point sample, however, and cannot detect previous desiccation damage in a seedling rewatered after damage has occurred (Cleary and Zaerr 1980). It is also not a measure of a seedling's vitality; dead seedlings can have normal or low moisture stress values.

Changes in a seedling's water status incurred during packing, storage, and handling can also be estimated from measuring the relative moisture content derived from fresh and dry weights[6]. If other alternatives are not available measuring the seedling water content may be useful, but calibration between actual water content measured this way and xylem water potential would need to be established first (Ritchie 1984).

Cold-hardiness testing

There are many situations in which a forester or nurseryman would like to assess the probable frost tolerance of planting stock. In a reforestation program, it may be necessary to know to what degree low temperature can be tolerated by different seedling stock in order to match the most appropriate plants to sites with potentially high levels of cold temperature. If tree seedlings are subjected to temperatures below their hardiness threshold after planting, mortality is substantial. Hence, cold hardiness should be considered a key seedling quality attribute (Ritchie 1984). In nursery production, knowing the frost tolerance of stock helps to determine when to apply irrigation for frost protection, assists decision-making related to the conditioning and overwintering of containerized stock, and helps to estimate the readiness of seedlings for fall lifting.

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[6] Navratil, S. 1978. Provisional sampling producers for monitoring plant stock quality in storage. 1. Moisture contents in stored seedlings. Lakehead Univ. Sch. For., Thunder Bay, Ont. Unpublished report.

Several tests have been developed to quantify variation in the frost tolerances of different planting stock (Timmis 1976; Warrington and Rook 1980). The most practical method of evaluating seedlings' response to low temperature is to expose them to a freezing cycle in a programmable freezer. The amount of damage that occurs in a freezing test is dependent on the minimum temperature attained during the test and on the rates of freezing and of thawing, as well as on the duration of the low temperature period (Warrington and Rook 1980). The use of equipment such as a programmable freezer is essential for a reproducible test to be performed and for making it possible to set up any temperature cycle required.

Frost hardiness testing using a programmable freezer is simple. Samples of seedlings are subjected to freezing treatments repeated across a range of temperatures. After each freezing treatment, the seedlings are placed in a growth chamber or greenhouse, and frost injury or damage is assessed visually. From the response of seedlings to this range of low temperatures, the minimum temperature at which 50% of a test population is killed is determined. This minimum temperature, which is called the median lethal temperature or LT 50, is then used to define the hardiness level.

Several methods have been proposed for assessing frost damage immediately after the freezing test, which avoids the time delay required for damage to become visually apparent (Timmis 1976). The electrical impedance and diffusate conductivity methods provide the most reliable results of immediate assessment of frost damage (van den Driessche 1976b; Ritchie 1984).

Frost hardiness of planting stock can be accurately evaluated with the methods now available to nurserymen. Freezing tests are gaining importance in operational production of bare-root and, in particular, containerized stock. The results of freezing tests, if correctly interpreted, can be very useful in preventing severe damage due to either early frost or low temperature stresses in overwintered stock. Such assessments may be particularly important in a centralized nursery that is growing seed lots from different latitudes and altitudes that differ vastly in frost hardiness levels. Freezing testing for cold hardiness is routinely used for stock quality evaluation in Douglas-fir nursery production, and practical application of this criterion in the field is becoming increasingly accepted by reforestation foresters.

The high initial capital cost of a programmable freezer must be considered from the perspective of the value of the nursery crop whose quality is being protected[7]. Other potential uses for cold hardiness testing are in predicting the poststorage quality of fall-lifted planting stock and indirectly in estimating the readiness of stock for fall lifting[8] (Burdett and Simpson 1984).

Nutrient analysis

The health and vigor of conifer seedlings depend to a great extent on an adequate supply of mineral nutrients. The potential exists to control the physiological conditions and quality of stock by providing specific fertility conditions in the nursery. Potassium, phosphorus, and nitrogen may affect cold hardiness, dormancy, stress resistance, and growth after planting (van den Driessche 1980); however, these effects are highly variable.

Because the effects of mineral nutrition on seedling physiology are complex and interacting, no consistent relationship has yet been demonstrated between any aspect of seedling nutrient content and seedling quality, except in cases of severe deficiency (Ritchie 1984). Nutrient analyses of seedling tissues can uncover nutrient imbalances prior to the appearance of visible symptoms of deficiency. If the results of these analyses are available quickly, they can guide corrective fertilization and prevent severe declines in seedling quality.

Hormones

Virtually all seedling growth processes are modulated by a changing balance of several plant hormones and inhibitors. These substances occur in minute quantities and are difficult to analyze. Limitations in analytical methods in the past have slowed satisfactory understanding of the role of hormones in forest tree seedlings (Zaerr and Lavender 1980), and few studies relate these compounds to seedling vigor.

Recent advances in analytical techniques should permit more accurate evaluation of hormone levels and consequently a better understanding of how they affect stock quality. The equipment and technology necessary for the analysis of hormones is sophisticated, expensive, and limited to specialized research laboratories. Studies into the role of hormones in forest tree seedling growth have been initiated at the Northern Forestry Centre, Edmonton, Alberta.

[7,8] Simpson, D.G. 1983. Cold hardiness testing. A paper presented to the B.C. Forest Nurserymen's Association Meeting, Surrey, B.C., February 22–24, 1983.

Carbohydrates

Carbohydrates—sugars and starch—are the primary food reserves stored in seedling tissues. Studies have been conducted to investigate the importance of adequate food reserves to seedling performance and the possibility of using carbohydrate content as a measure of seedling physiological condition (Puttonen 1980) or as an indicator of decline in postplanting vigor (Hellmers 1962; McCracken 1979).

Severe respiratory depletion of reserve carbohydrates occurs in lifted and stored seedlings (Navratil 1977, 1982; van den Driessche 1979; Puttonen 1980; Ritchie 1982). Food reserve loss during storage has been implicated in poor survival and poor root potential (Hellmers 1962; Stone and Jenkinson 1970; Farmer 1978), although a cause-and-effect relationship between carbohydrate reserves and root growth potential may not always be involved (Ritchie 1982).

Carbohydrate analysis of seedling tissues is complicated, primarily because of conversions among carbohydrates and between carbohydrates and other food reserves such as hemicellulose, fats, and proteins (Glerum 1980). Although carbohydrate assessment may hold promise as a future tool for indicating seedling quality (Ritchie 1984), no practical technology is currently available.

CURRENT PRACTICES

All nurseries surveyed gather some stock quality information. This information is based mostly on morphological criteria that is primarily obtained from quality checks during grading and packing (Table 1). Morphological measurements appear to be favored over physiological characteristics of the seedlings. Moisture stress measurement is used more to monitor stress in seedlings during lifting and packing than as an index of seedling quality. Much attention is given to culling of seedlings that show signs of damage or abnormal morphology. Seedlings exhibiting insect injuries, disease symptoms, wounds, torn roots, multiple leaders, or crooked roots are normally culled. Grading is based solely on morphological attributes, primarily height and root collar diameter and estimates of root system size. Intensive outplanting tests in nurseries are commonly established. They will likely provide a valuable source of data for comparisons of seedling quality and history, cultural practices, and performance after outplanting.

It appears that current practices do not take advantage of the many reliable techniques available for assessing seedling quality. Established operational monitoring systems appear deficient both in methods to assess physiological criteria and in methods to express the overall status of a seedling's quality that are closely correlated with postplanting performance (such as root growth potential and stress resistance). This review of the completed questionnaires indicates a pressing need for standardization of acceptable methods for assessing seedling stock quality. Without this step, which most feasibly would be presented as a manual for monitoring stock quality and survival and growth in the field, valid comparisons may not be possible.

Table 1. Morphological and physiological characteristics of seedlings assessed in the prairie provinces (a summary of responses to the questionnaire)

Characteristic	Alberta	Saskatchewan	Manitoba
Morphological			
Height	X	X	X
Root collar diameter	X	X	X
Root area	X	Size estimated	—
Top dry weight	X	X	X
Root dry weight	X	X	X
Shoot/root ratio	X	X	X
Top fresh weight	X	—	X
Root fresh weight	X	—	X
Physiological			
Moisture content	X	—	X
Moisture stress	X[a]	—	X[b]
Root growth potential	X	—	In 1985
Tissue analysis	X	X	In 1985
Outplanting tests	X	X	X

[a] Experimental basis.
[b] At packing.

The minimum morphological standards that are currently in use to identify acceptable seedlings apparently reflect provincial requirements and experience. They may not reflect stock performance, however, and may not have been determined through evaluation of seedling survival and growth after outplanting. As better information becomes available from

the quality and performance monitoring programs discussed in this report, these standards can be upgraded and expanded by incorporating seedlings' physiological and, primarily, performance attributes. Considerations and processes involved in developing and defining the new quality standards of forest nursery stock are discussed thoroughly by Burdett (1983).

SUGGESTIONS FOR IMPROVEMENT

A high-quality seedling is expected to survive and grow on a particular site. The factors involved in improving this performance, particularly the relationships that control responses to specific site conditions, are not yet fully understood. In contrast, the mechanics of measuring many seedling attributes are for the most part well known. What is missing is a link connecting the measurement of seedling quality prior to planting with seedling performance after planting. In order to upgrade reforestation programs, managers need an improved flow of information about the relationship between estimates of seedlings' quality and performance on various sites. At present many reforestation programs suffer from a lack of information integrating stock quality, outplanting performance, and planting site details (Vyse and Navratil 1985).

Monitoring of stock quality in a nursery can fulfill the requirements of quality control at the nursery level and provide reasonable stock description for reforestation foresters. Given low stress situations, when seedlings are subjected to a minimum of handling and only a short transit before planting, it may function well. In many other situations the opposite is true and one-level monitoring is inadequate. The biggest problems with bare-root stock are those that result from prolonged storage, transit, handling, and holding. Seedling quality may be lost or seriously deteriorate between the time of shipping from the nursery and time of planting in the field; therefore, quality monitoring must extend beyond the nursery gate. Taking stock quality monitoring out of the nursery and research laboratory and finding ways to make it an effective part of an everyday reforestation program are formidable but essential tasks.

A mobile team of trained personnel with a minimum of equipment could assist in the field in several ways. Such a team would be particularly useful in carrying out or facilitating on-site stock quality assessment, in trouble-shooting and investigating the causes of unsatisfactory seedling performance, in setting up a network of assessment plots, and simply in communicating with the field foresters. Close cooperation and communication with field personnel is essential for fast and meaningful exchange between nurserymen and reforestation managers. The importance of making relevant data available to the forest manager as soon as possible cannot be overemphasized. The forest manager is often under a great deal of pressure to act and needs whatever data can be obtained.

An integrated stock quality monitoring system should include many components: stock quality monitoring in the nursery, stock quality monitoring on the planting site, assessment of plantation performance and its relation to site conditions, interpretation of the plantation results, and feedback to nursery production (Fig. 1). Selected seedlots should be followed from the nursery through handling to the planting site and should be subjected to postplanting assessments. Use of standard field assessment methods will be needed to satisfy statistical considerations and ensure reliable feedback on performance. Standardized design of the assessment plots and their measurements, forms for data recording, and centralized data processing would facilitate interpretation and hasten application of results. Survival figures are inadequate to evaluate plantation establishment; measurements that reflect growth and the evaluation of cost factors (Hallett and Cameron 1983) may need to be included.

The resulting network of trial plots established with seedlings having defined quality attributes planted over different site conditions will provide information for the production of seedlings in the nursery that is more closely tailored to the needs of the site. An adequate evaluation of stock quality will make it possible for foresters to specify stock needs in more detail and in relation to planting site conditions.

There is a definite need for a site classification system in the prairie provinces, similar to that proposed by Corns and Annas (1984), that will enable the forester to develop the most effective reforestation prescriptions. A practical site classification system would facilitate trade-offs among seedling quality, site conditions, and site preparations. The ultimate goal would be to refine the techniques of matching seedling quality to site conditions, which in turn would allow full expression of site potential.

Currently, the predictive value of seedling quality attributes are assessed mostly by comparison with those

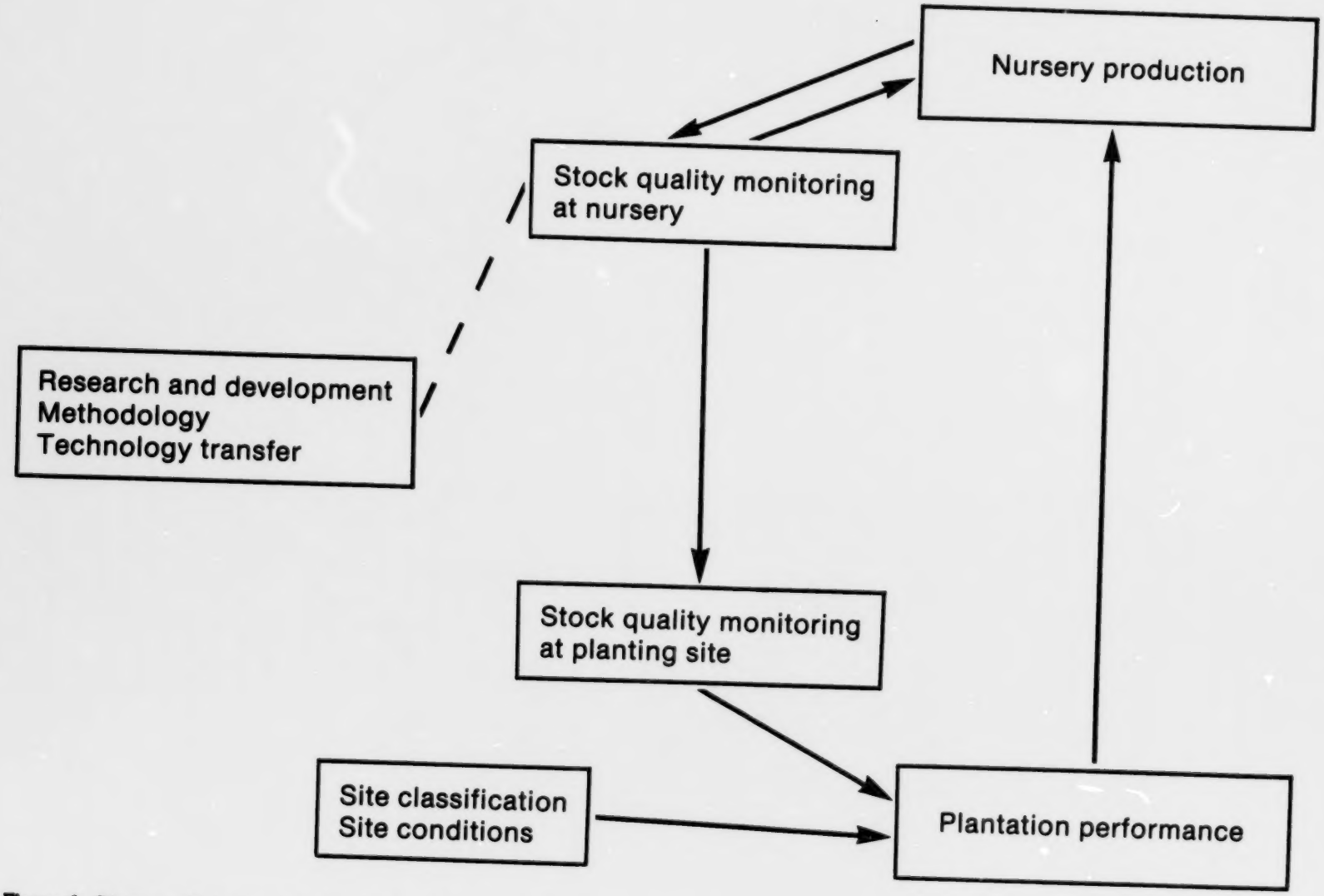

Figure 1. Diagram of integrated stock quality and plantation performance monitoring program.

criteria that provide the best correlation between quality and performance. Whether a change in the magnitude of these seedling quality attributes could bring about a corresponding improvement in field performance is largely untested. Likewise, the optimal and minimal threshold levels of quality attributes are mostly unknown. The task of defining the threshold values of many quality criteria should be addressed through coordinated research and field trials. With a few exceptions at present, a seedling quality attribute measurement can be interpreted and used for actual reforestation decisions only if the value it normally takes in healthy well-performing seedlings is known. Defining a threshold value that is just sufficient to guarantee good performance under given conditions is difficult and requires years of empirical research trials and reliable feedback on the performance of stock conforming to known standards (Burdett 1983). Much faster progress could likely be achieved with a well-functioning integrated system in which both seedling quality and plantation performance are monitored as proposed above.

Many methods and techniques that are available for measuring attributes of seedlings have been adequately tested in practice and can be accepted without much additional work. It should be possible to select these from various regional stock quality manuals (Duryea and Landis 1984; Day et al. 1985), although some degree of adaptation and calibration to specific local conditions will be required. Methods and procedures in the literature are described in terms suited for laboratory and research personnel, and many methods are presented in scattered publications with specifications for the same method varying from source to source. In order to achieve the objectives of regional standardization and unity, a manual that compiles methods for stock quality evaluation and describes the techniques and procedures in a hands-on cookbook form should be prepared. This manual should be supplemented by at least minimal training of operators through workshops or demonstration sessions.

CONCLUSIONS AND RECOMMENDATIONS

Nursery management and plantation establishment represent a great concentration of technology and investment in the Alberta, Saskatchewan, and Manitoba reforestation programs and are therefore in a unique position to benefit from an intensive approach to stock quality control.

The brief overview presented in this paper shows that there is a considerable body of knowledge in the field of stock quality evaluation that can be utilized and managed to the benefit of nursery production and plantation establishment.[9] In contrast, current stock-quality monitoring efforts do not appear adequate because of (a) limited attention to physiological stock quality criteria; (b) a lack of monitoring beyond the nursery; (c) unknown threshold levels of quality criteria pertinent to local species and conditions; and (d) poor information flow about plantation performance and its relation to stock quality and nursery production.

An integrated stock quality and plantation performance monitoring program carried through all components of the reforestation cycle—stock quality monitoring in the nursery, stock quality monitoring on the planting site, plantation assessment, and interpretation and feedback to nursery production—needs to be initiated. Such a program will help to overcome these shortcomings and to realize fully the potential of stock quality monitoring and the consequent benefits from improved nursery production and regeneration success.

Coordinated stock quality assessment research and development supported by comprehensive and systematic two-way technology transfer is urgently required to provide the background and necessary support to realize this program. Several steps should be undertaken, as outlined below.

Recommendations for a technology transfer program:

(a) A manual of methods for assessing stock quality should be prepared and gradually upgraded as new methods that have been tested in practice become available. This can be accomplished through critically selecting and combining available hands-on methods from other regions such as Ontario, Oregon, and British Columbia.

(b) Demonstrations, workshops, and training sessions on how to evaluate stock quality and how to maintain the quality of stock during handling and other operations should be organized.

(c) Statistically verified, standardized procedures for establishing experimental plots for plantation performance assessment should be prepared.

[9] Also see: Duryea, M.L. 1985. Evaluating seedling quality: principles, procedures and production abilities of major tests. Oregon State Univ., Corvallis, Oregon. This publication has not been discussed in the present report.

(d) Advisory and consultative assistance should be provided to assist in standardization and upgrading of the current provincial monitoring programs and to assist in setting up the framework of integrated stock quality and plantation monitoring programs.

Recommendations for research and development:

(a) Methods for stock quality evaluation not directly transferable from other sources should be tested and adopted and recommendations provided on their suitability, practicality, and equipment specifications.

(b) The threshold quality criteria of planting stock in relation to postplanting performance and site conditions should be defined. This is a major task that will require the coordinated effort of federal and provincial research programs. A considerable data base will have to be accumulated from field trials with seedlings of known quality attributes that are established on various sites.

(c) An information base for improving nursery production of stock types and stock quality grades better adapted to specific site conditions should be gradually accumulated.

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APPENDIX 1

PLANTING STOCK QUALITY QUESTIONNAIRE

Questionnaire on Planting Stock Quality Monitoring (Bare-root stock only)

Rationale for stock quality monitoring in nursery:

1. To provide for year-to-year comparison of crops, which would enable nursery staff to make changes where necessary to meet prescribed standards;

2. To provide additional in-house quality control data which would be useful in responding to any complaints about stock which may arise;

3. To encourage field foresters and nurserymen to work together in setting and achieving optimal stock characteristics, and to generally improve stock-quality communication between field and nursery.

Objectives of the questionnaire:

1. To facilitate exchange of information on stock quality monitoring between the provincial nurseries;

2. To compare the methods of planting stock monitoring;

3. To provide a basis for standardization of the methods used in stock quality monitoring, thus facilitating comparisons of outplanting performance of various types of stock.

Morphological quality of stock (size characteristics)

1. In culling/grading by size for packing do you use as standards:

   _____ Height

   _____ Root Collar Diameter (RCD)

   _____ Combination of Height and RCD

   _____ Size of root system

   _____ Other (specify)

2. In monitoring stock quality for morphological characteristics do you sample:

   _____ in nursery beds prior to lifting

   _____ at the time of sorting/packing

   _____ prior to shipment from packed containers

   _____ Other (specify)

3. Do you take samples for monitoring from:

   _____ each seedlot

   _____ each shipment

   _____ each nursery compartment

   _____ Other (specify)

4. What is the size of samples you use in monitoring? Describe: _____

   _____

   _____

   _____

5. What sampling procedure do you use? Describe: _____

   _____

   _____

   _____

6. In monitoring morphological characteristics of stock, check yes/no what attributes you assess and what methods you use:

YES	NO	
_____	_____	Height (top length, root collar to terminal bud)
		Other: _____
_____	_____	Root collar diameter (stem diameter, calliper)
		_____ at root collar
		_____ slightly above (0.5 cm?) root collar
		_____ other
_____	_____	Top volume (by water volume displacement)
		(by other method): _____
_____	_____	Root volume (by water volume displacement)
		(by other method): _____
_____	_____	Top area: _____
_____	_____	Root area (Root surface area, root area index):
		_____ by rhizometer or other photoelectric devices
		_____ other methods (specify) _____
_____	_____	Top dry weight:
		_____ by oven-drying at 70° for 24-48 hours
		_____ by drying at other temperatures (specify) _____
_____	_____	Root dry weight:
		_____ by oven-drying at 70° for 24-48 hours
		_____ by drying at other temperatures (specify) _____
_____	_____	Top fresh (green) weight
_____	_____	Root fresh (green) weight
_____	_____	Estimates of fibrosity (quality) of root system (If yes, describe what methods you use)
_____	_____	Other (specify) _____

Physiological Characteristics

7. In monitoring stock quality for physiological characteristics do you sample:

_____ in nursery beds prior to lifting

What characteristics:

_____ plant moisture stress

_____ other (specify)

_____ at the time of sorting/packing

_____ prior to shipment from packed containers

8. Describe frequency of sampling, size of samples, method of sampling you use in assessments of physiological quality: _____

_____

_____

_____

_____

_____

9. Check which of the following physiological attributes/method are included in monitoring stock quality in your nursery:

YES NO

_____ _____ Plant moisture stress by pressure bomb

_____ prior to lifting

_____ at the time of sorting/packing

_____ at the time of shipping

_____ _____ Percent moisture content of seedlings

$$\left(\frac{\text{fresh weight - dry weight}}{\text{dry weight}}\right) \times 100$$

_____ at the time of sorting/packing

_____ at the time of shipping

_____ other: _____

_____ _____ Root regeneration capacity

_____ by potting the seedlings in greenhouse or growth chamber (e.g. Burdett's test)

_____ other method: _____

_____ _____ Tissue analysis for element content:

_____ macronutrients

_____ micronutrients

State of dormancy/hardening-off/readiness for fall lifting is estimated:

_____ by experience

_____ by incidence of growing root tips

_____ using oscilloscope

_____ using impedance/resistance meters

_____ using cumulative degree hardening days

_____ other (specify) _____

General appearance/damage/disease/injury

10. Check which of the following are used as criteria in culling and/or recorded in monitoring the stock quality:

	Culling	Recorded in quality monitoring
Insect damage	_____	_____
Fungal disease	_____	_____
Twin tops	_____	_____
Multiple leaders	_____	_____
Crooked stems	_____	_____
Crooked roots (45° angle or more)	_____	_____
Chlorotic foliage	_____	_____
Deficiency symptoms	_____	_____
Torn roots with penetration to wood	_____	_____
Mechanical wounds on stem	_____	_____
Other (specify)	_____	_____

Monitoring of stock quality by assessing performance after outplanting tests in nursery.

Indicate what size of sample is used in outplanting tests in your nursery:

No. of trees outplanted in each sample: _____

In _____ _____ _____ _____ replicates
2 3 4 or more

What is the sampling frequency:

_____ from each seedlot

_____ from each shipment

_____ other (specify) _____

Sampling method: How do you select the sample/seedling for outplanting tests:

_____

_____

_____

_____

Check which of the following parameters are used in performance assessment of outplanted seedlings:

Survival after one year _____
two years _____
other _____

Height increments after one year _____
two years _____
other _____

Root collar diameter increments _____

Increase in root volume area (root regeneration/growth estimates) (by destructive sampling) _____

Estimates of degree of damage:

	the first	second	_____ growing seasons
chlorosis	_____	_____	_____
loss of needles	_____	_____	_____
dead terminal bud	_____	_____	_____
dead terminal	_____	_____	_____
other (specify)	_____	_____	_____

General comments or suggestions:

_____

_____

_____

_____

_____

_____